CRANFIELD INSTITUTE OF TECHNOLOGY

RADIAL INFLOW TURBINE STUDY

FIFTH INTERIM REPORT

by

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The radial inflow turbine is a primary component used both in small gas turbines and turbochargers. Better understanding of the flow processes occurring within the small passages of the machine could well result in the improved design of units. As most of the detailed aerodynamics is still ill-defined, a joint research project with the objective of improving our understanding has been instigated by Cranfield, the US Army and Turbomach (San Diego).

This document gives the fifth report on the project. It describes the early attempts at obtaining measurements downstream of the rotor and provides some results.

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During the period starting from January 1991, manufacturing modifications to the test assembly required to carry out the laser anemometry work have been completed. Figure 1 shows the location and design of the optical windows at two different positions downstream of the turbine rotor. Provision to clean the window during operation has also been provided.

Test assembly was installed on the rig after the machining of two windows and the turbine unit was run for different speeds by controlling the flow rate at the turbine inlet. Software was also modified to obtain values for U/V_o along with pressure ratio and speed during the operation. As mentioned in the third interim report, it was proposed in a meeting, with C Rodgers representing Turbomach, that the pressure ratio at which laser measurements be made should be above 3.0 while the velocity ratio U/V_o should be kept at 0.75, 0.65 and 0.55. The turbine was run at pressure ratios 3.0, 3.5, 4.0 and 4.5. Various turbine characteristic parameters have been tabulated in Table 1 for these pressure ratio values.

For the initial studies it was decided to run the unit at 3.5 pressure ratio with U/V_o equal to 0.64. During initial runs with the turbine at this condition it was observed that the turbine outlet temperature dropped to $-16.2^\circ C$ which caused a layer of ice on the glass window preventing any laser anemometry measurement. Through experience it was found that after a run of at least 30 minutes the temperature of the inlet ducting rose and the turbine inlet temperature became $70^\circ C$ bringing the outlet temperature to $-3^\circ C$. Even at this temperature, the optical window becomes wet and water droplets appearing on both sides of the window distorted the laser beams.

In order to keep the window dry and to get a better laser signal, it was necessary to modify the optical window design shown in Figure 1. It was thought advantageous to bring the window away from the duct using a pin hole near the inner wall of the duct, as shown in Figure 2. Recent experience at Cranfield on similar work shows that the use of a pin hole, the size of which depends upon the measurement volume positions, reduces the background noise and improves the signal to noise ratio.

The rig was run after these design modifications but the window was still found wet. In order to keep the window completely dry, a small proportion of the hot air from the turbine inlet was bled through a tube and was directed to the glass window. The air was warm enough to keep the window moisture-free.

The Malvern laser system is being used in time-of-flight mode which means that the optical system has to be rotated to align the velocity vectors with the plane containing both laser beams. Therefore it is advantageous to have a prior knowledge of flow direction as a guide. Attempts were made using the white solid seed particles (the details of which have been included in the fourth interim report) to trace their flow direction on the downstream duct walls. This technique has been employed successfully on other occasions but in this case the condensed liquid on the duct wall did not leave any powder traces, so an estimated flow direction has been assumed to carry out further works.

For the current studies the silicon oil has been used to seed the flow as the temperatures involved are not high. The immediate problem encountered in the laser anemometry work is the presence of large numbers of condensed liquid particles in the flow which, although serving as natural seeding, cause a lot of background noise.

Currently attempts are being made to overcome these problems by increasing the turbine inlet temperature. One option is to heat the inlet air up to 200° C thereby increasing the turbine outlet temperature to avoid condensation. Another proposal is to control the air through the ejectors which has been used to obtain a higher pressure ratio across the turbine.

Laser Anemometry Results

Laser anemometry work was carried out first for window A (Fig 1). The unit was run for half an hour to increase the turbine inlet temperature from 20° C to 80° C which brought the turbine outlet temperature up to 12° C. The glass was removed and the window blanked by a metal plate during this warming up session.

Once the required outlet temperature was obtained, the window was installed and the bleed air from the turbine inlet turned on to avoid any condensation on the plate.

As a preliminary step, it was decided to carry out the laser anemometry work at presure ratio 2. Different radial positions (P_1, P_2, P_3 ....) were selected at window A as shown in Figure 3. The laser beams were focussed at position P_1. The optics inside the Malvern laser system were rearranged to bring the spots along the line perpendicular to the machine axis. The system was then rotated clockwise to map the flow. Figure 4 shows the datum line chosen in order to define the flow angle θ.

Seeding was turned on and a reasonable signal was observed at position P_1 and results were found repeatable. Laser beams were then focussed to positions P_2, P_3 and P_4. Table 2 shows the averaged results for these positions at pressure ratio 2.0. After the positions P_4 (14mm from the window, as shown in Fig 3), seeding response was very weak and no result could be obtained beyond this position.

The pressure ratio was then changed to 2.2, 2.5, 2.8 and 3.0. It was found difficult to carry out laser work for high pressure ratios (2.8 and 3.0) as the condensation occurs and the liquid particles start creating strong background noise. Results were obtained at positin P_1 for these pressure ratios but no satisfactory results could be obtained beyond this position. Table 2 gives the complete set of measurements at different positions for various pressure ratios.

Figure 5 shows the expected gradual increase in the velocity at positions P_1 as the pressure ratio is increased from 2.0 to 3.0. Figure 6 shows very little variation in the flow angle at positions P_1 as the pressure ratio increases.

Variation in velocity and flow angle at positions P_2 for various presure ratios have been shown in Figures 7 and 8. Figures 9 and 10 shows the same result for position P_3.

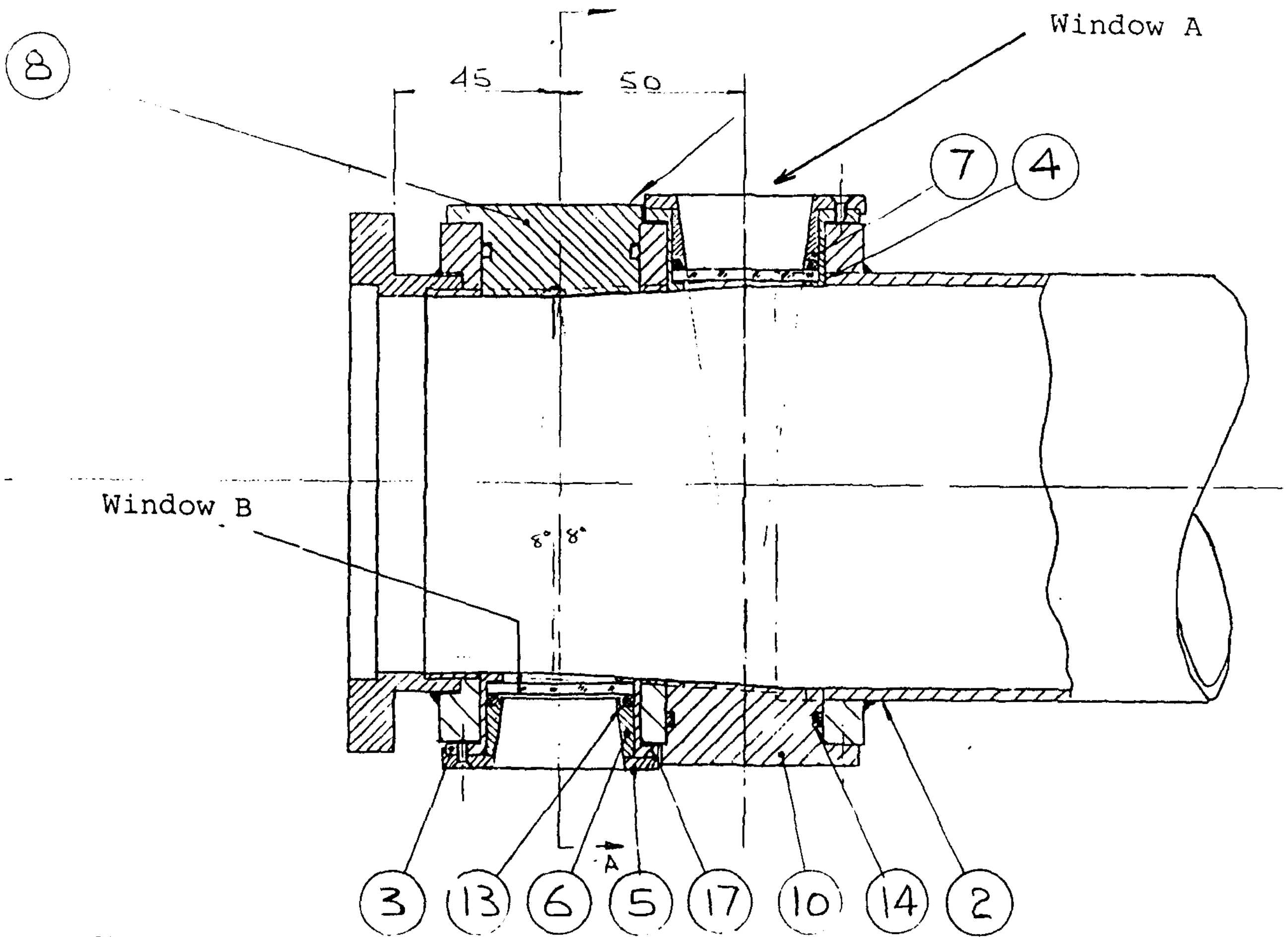
Currently attempts are being made to extend the range of measurements. Once the associated are resolved laser anemometry work, already in progress, will be carried out for all positions at both windows.

TABLE 1

PR	$\frac{U}{V_o}$	$\frac{N}{\sqrt{T}}$	T_{inlet} (C°)	T_{outlet} (°C)
3.0	.60	38.63	26.2	-15.7
3.5	.64	42.79	37.23	-16.2
4.0	.67	47.14	47.2	-15.8
4.5	.68	49.51	59.0	-13.1

TABLE 2

Pressure Ratio (PR)	Position	V (m/sec)	θ (degrees)	I (%)
2.0	P_1 P_2 P_3 P_4	34.8 31.1 26.9 25.0	34.57 34.55 35.00 34.45	10.27 12.27 11.64 8.85
2.2	P_1 P_2 P_3 P_4	37.4 32.7 29.3 27.6	35.56 34.77 34.61 33.29	10.36 13.54 11.80 10.24
2.5	P_1 P_2 P_3	40.9 35.8 32.9	36.56 38.10 37.91	11.10 13.45 7.50
2.8	P_1 P_2 P_3	44.5 36.4	33.31 36.60 37.20	5.33 - -
3.0	P_1	45.0	36.12	-



Note ; In practice both windows are on the same side.

FIG 1 ; WINDOWS FOR OPTICAL ACCESS

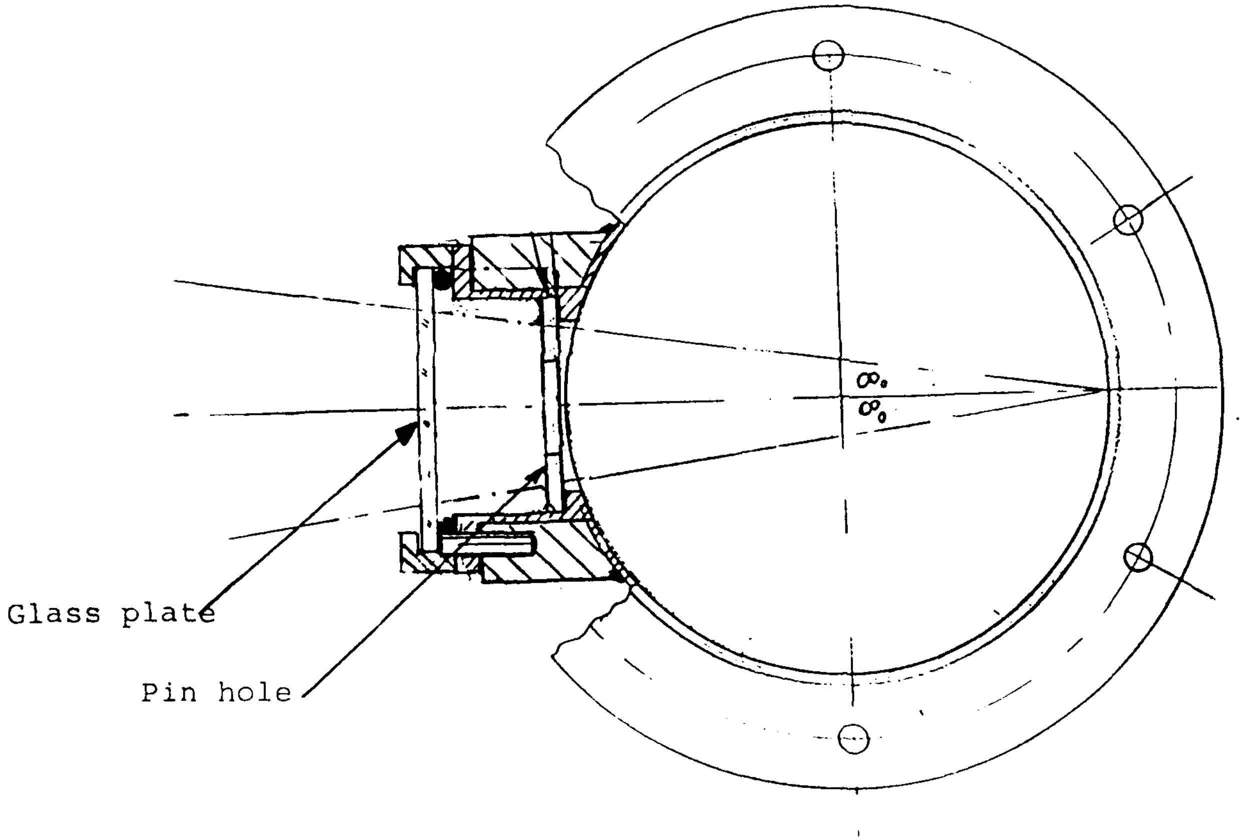
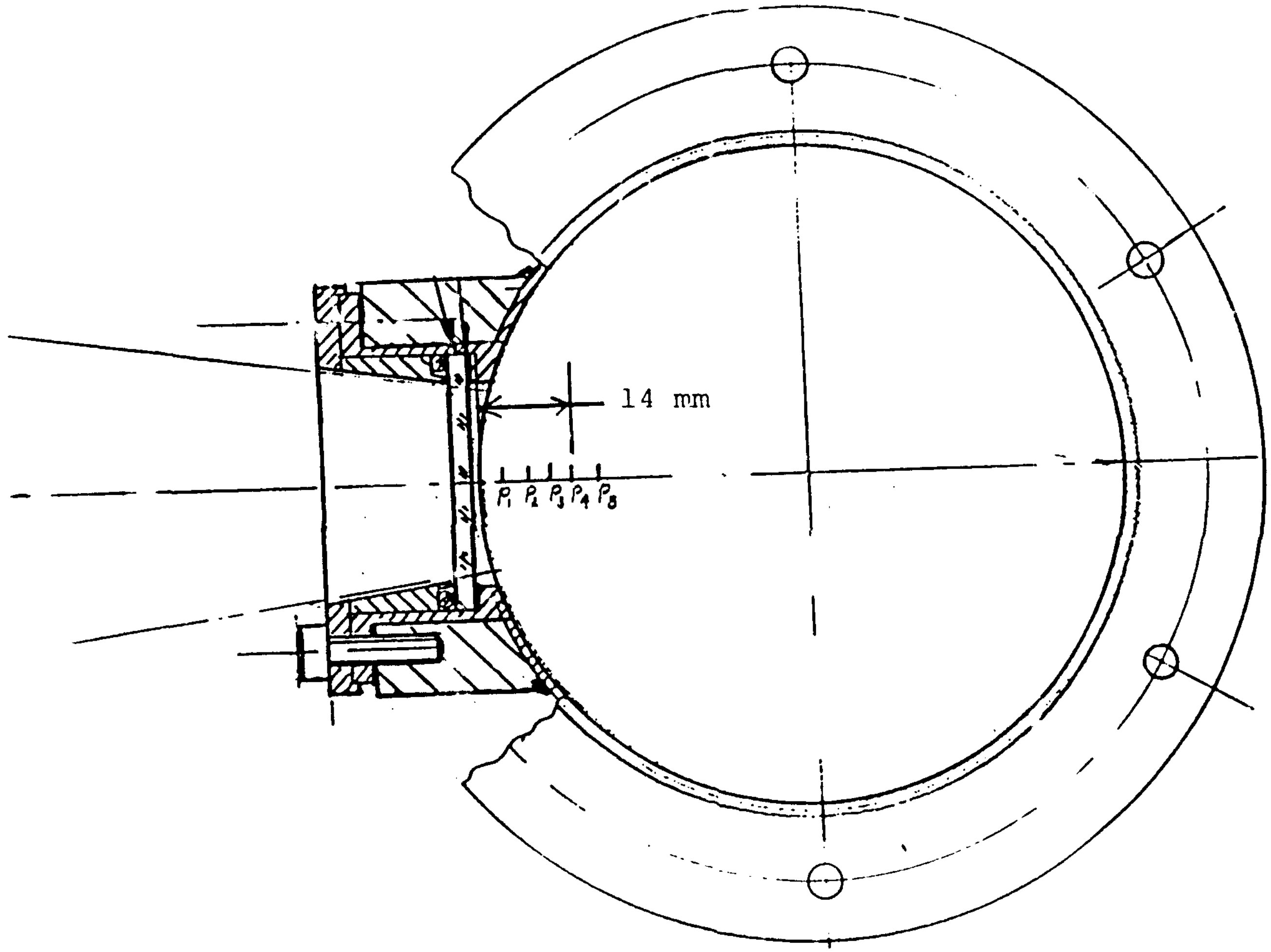


FIG 2 : REDESIGNED WINDOW WITH A PINHOLE ASSEMBLY



Note: Positions P_i are seperated by 3.5 mm

FIG 3 : POSITIONS P1,P2,P3.... AT WINDOW A FOR LASER ANEMOMETERY MEASUREMENTS

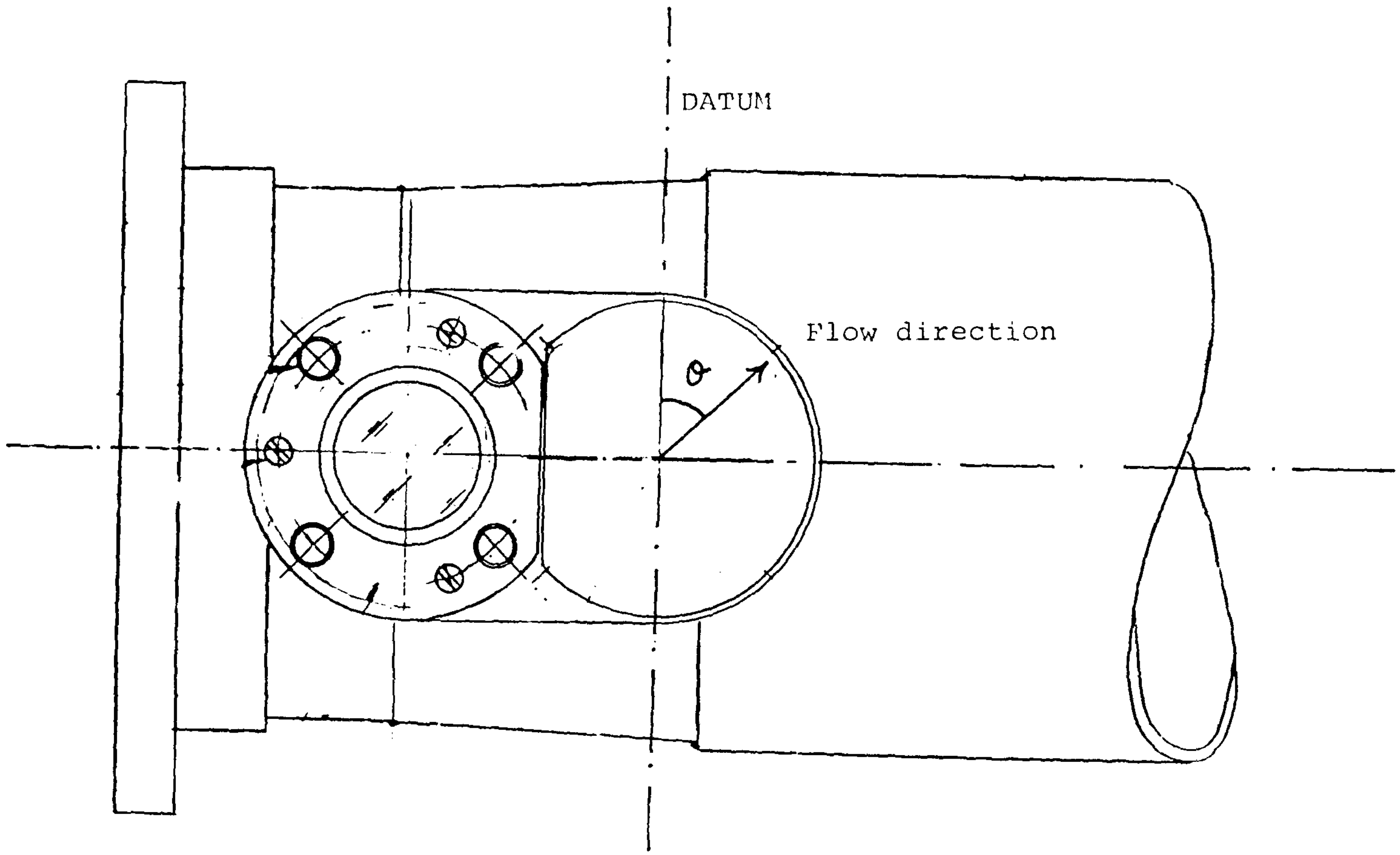


FIG 4 ; DEFINITION OF FLOW ANGLE θ USED IN LASER ANEMOMETRY RESULTS

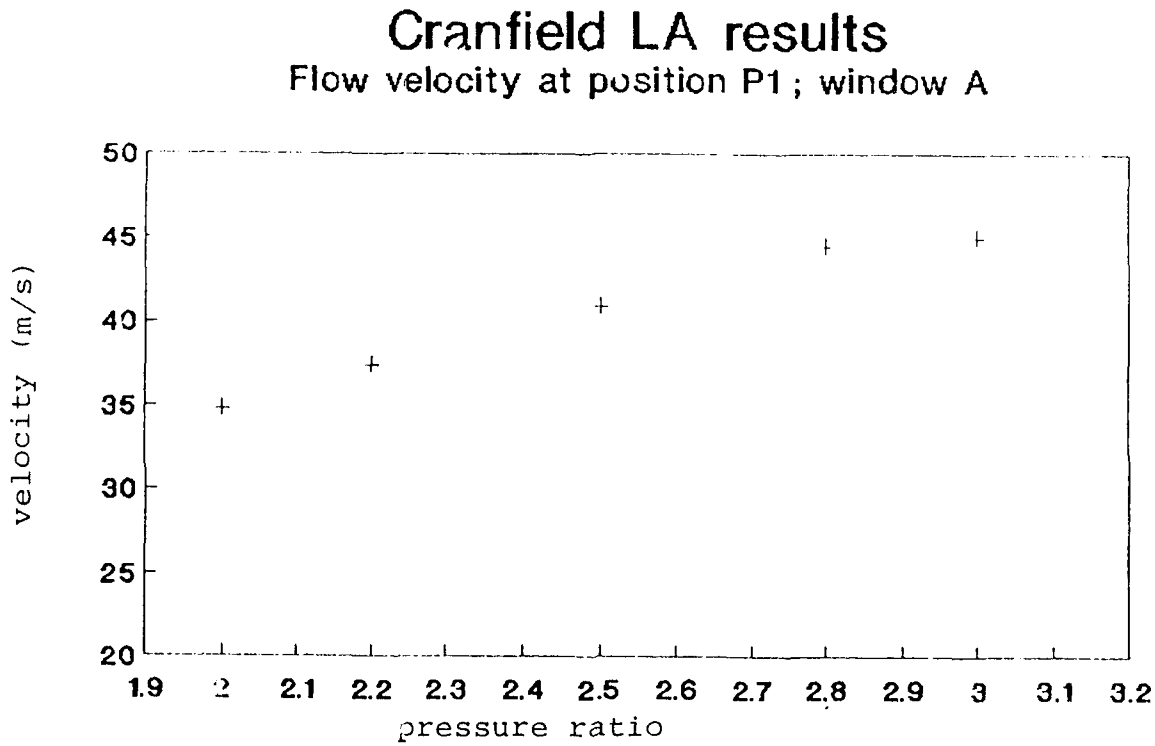


FIG 5 : LASER ANEMOMETRY RESULTS

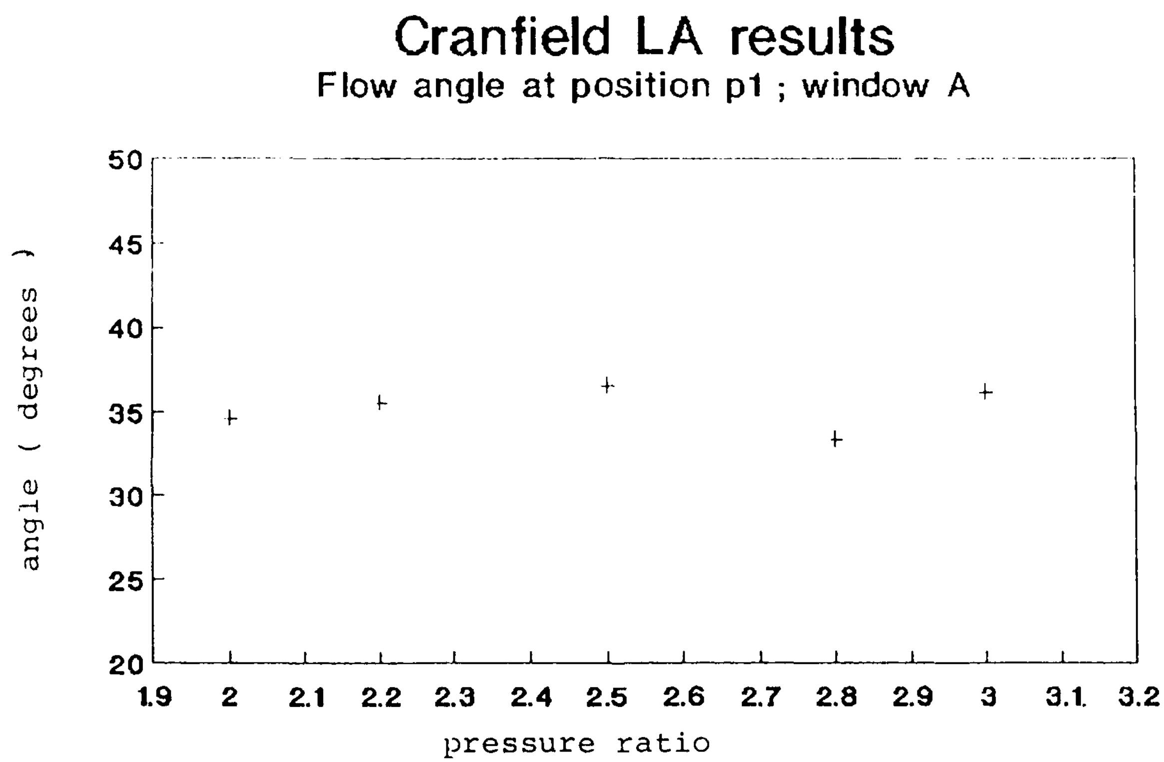


FIG 6 : LASER ANEMOMETRY RESULTS

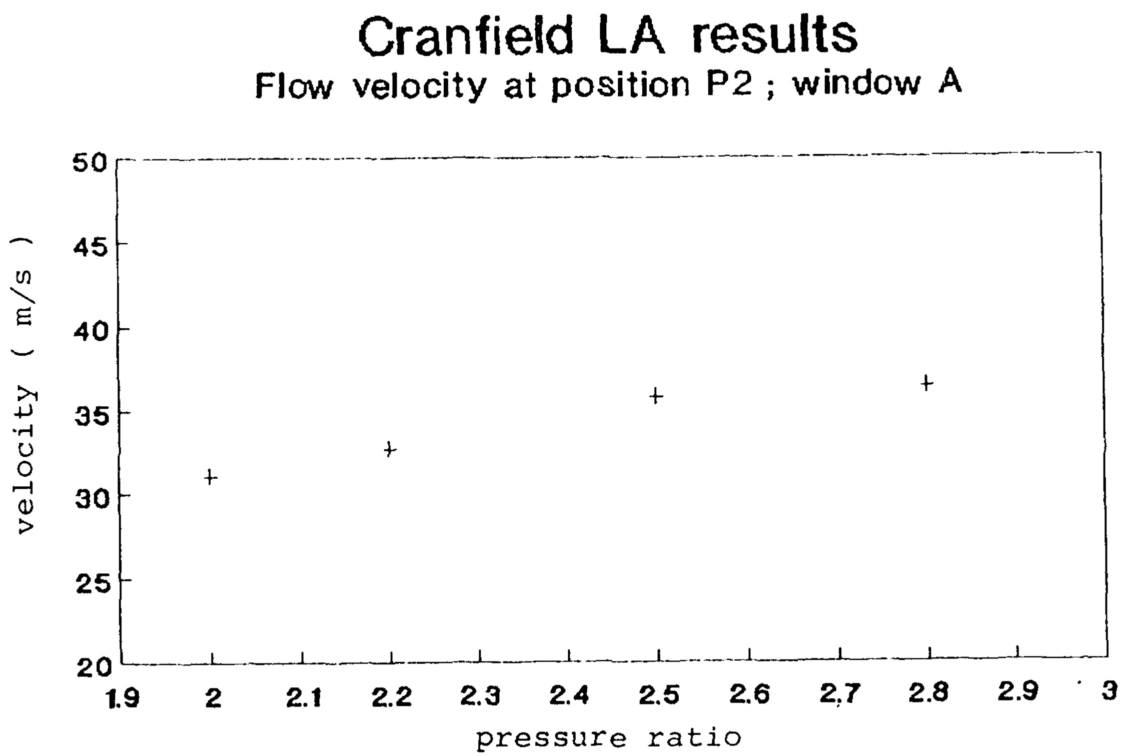


FIG 7 : LASER ANEMOMETRY RESULTS

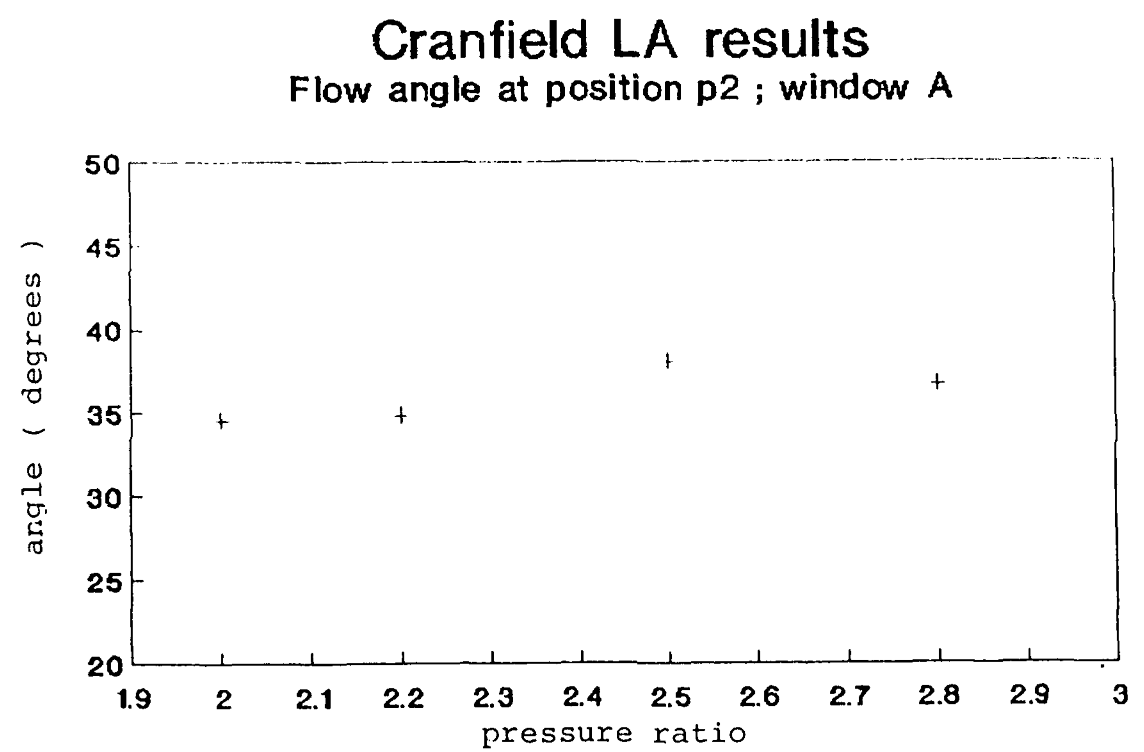


FIG 8 : LASER ANEMOMETRY RESULTS

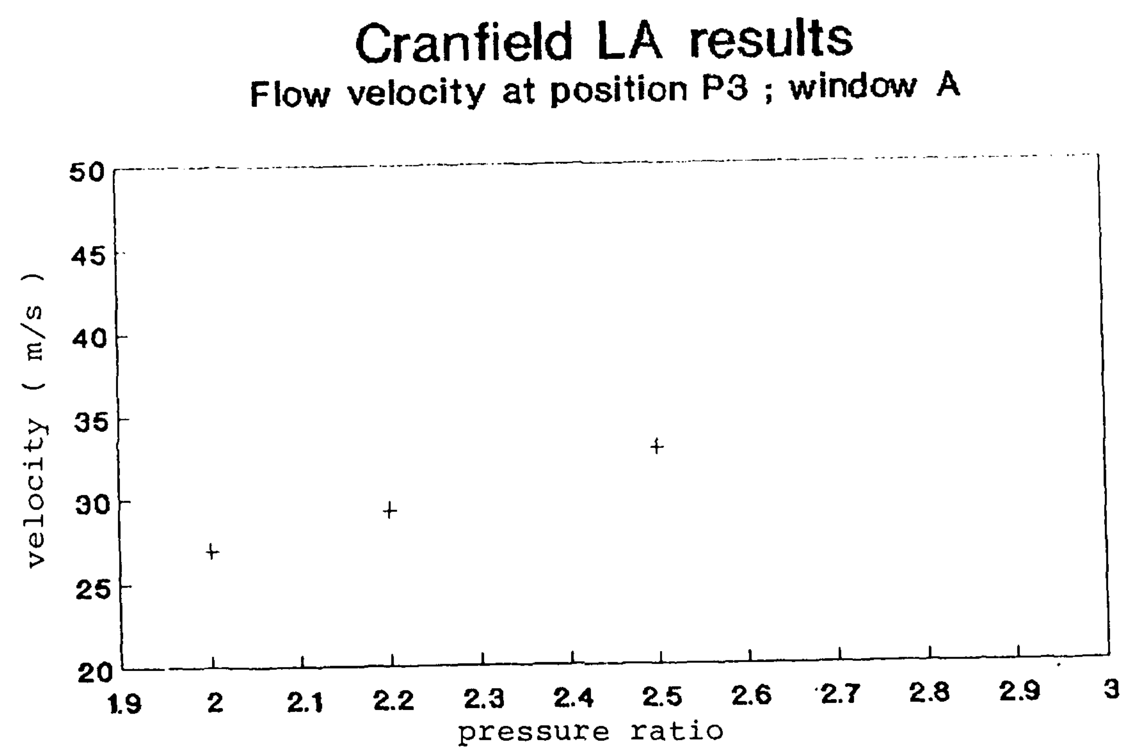


FIG 9 : LASER ANEMOMETRY RESULTS

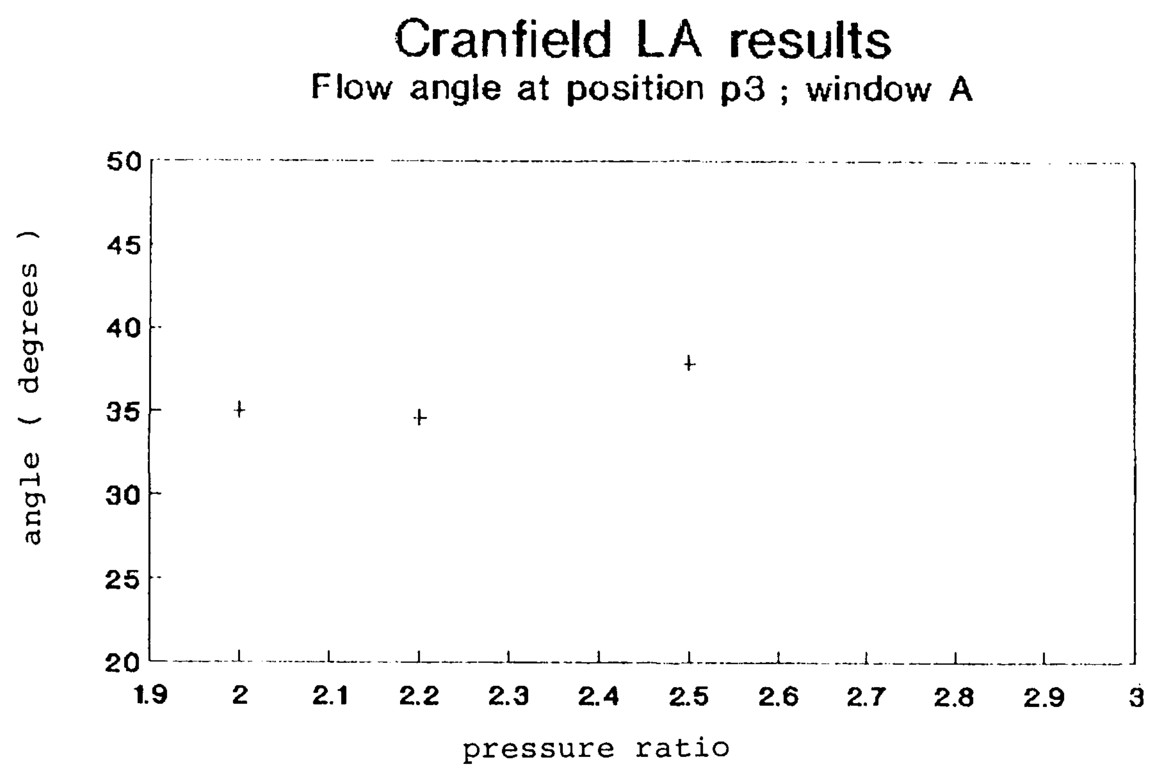


FIG 10 . LASER ANEMOMETRY RESULTS